Cognitive IoT Systems – the Future of IoT

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IoT – Current Status and Future Trends

The Internet of Things (IoT) has emerged in recent years as the main technology for "Digitalization" of different Industries, be it manufacturing or energy & utilities or transportation or healthcare or smart cities. IoT connects the physical and virtual worlds by giving sensing and processing capabilities to the physical "things". The "things" can be extended to sensing "people" and "processes" and is generally known as Internet of Everything (IoE) [1]. All such systems are typically characterized by a "Sense-Analyze-Respond" cycle [2], leading towards context-aware systems. With large scale proliferation of IoT technology in real-world deployments in the verticals of Manufacturing, Energy & Utilities and Smart Cities, the basic technologies of sensing, communication and cloud are getting matured and the focus is now shifting towards incorporating technologies for advanced security, artificial intelligence and edge computing and newer application verticals of Smart home and Healthcare [2][2].

By 2020, the IoT market size is estimated to be more than 450 Billion USD growing at an annual rate of approximately 30% with Smart Cities, Manufacturing, HealthCare and Smart Homes catering for more than 75% of the market. For the first time in the history of mankind, in 2018, the number of devices are already outnumbering number of people in our planet[3], giving credence to the phenomenal growth story of IoT.

In a recent book on IoT by the authors [2], we presented a detailed discussion on 'Real IoT' bringing out the key contributing factors of realistic implementations of IoT and outlined how a real implementation of IoT is always a trade-off between various features like hard & soft sensing, security & user experience, battery life & performance, communication range, power & bandwidth etc. It appears that that next wave of IoT will be driven by two key technologies – "Resilient IoT Systems" and "Cognitive IoT Systems". While the Resilient IoT systems will naturally emerge through engineering advancements of IoT technology, it is the Cognitive IoT Systems which will potentially disrupt the market through unique marriage of IoT Sensing with Artificial Intelligence.

What is Cognitive IoT and Why it is Needed

We define "Cognitive IoT" as an IoT system that integrates aspects of human cognitive processes in the system design to achieve `various levels of autonomy in perception, analysis and actuation supporting self-x capabilities including learning, re-configuration, resilience, optimization and management with adequate human-machine context awareness.

The underlying cognitive process can have many abstractions of a cognitive cycle such as 'Sense', 'Understand', 'Decide' and 'Act'. The 'Sense' process takes care of sensing and collecting data about the self the world around. 'Understanding' involves extraction of information through analysis of sensor data, interpreting and representing them in a structured manner. This is followed by a decision making process to arrive at responses and actions to be taken based on the information gathered. Finally the decisions taken are applied to the system through suitable actuation logic as part of the 'Act' process. At each of these stages the system can learn from experiences which can be used subsequently to adapt. Such intelligent control loops can provide a system with autonomic capabilities or self-x properties such as self-healing, self-configuring, self-optimization and self-management.

What it means to be a cognitive IoT (C-IoT) system? A C-IoT system should be able to detect any failures of its system components and re-configure itself to provide a graceful degradation through self-healing. If there is a sensor failure, the system should explore if it can be compensated using a soft-sensor or inference from remaining sensor data. When communication bandwidth is affected by an unforeseen interference source, it should explore if the flow can be re-routed or the data can be compressed or encoded with suitable error control codes as an adaptation measure. On the detection of a security attack on a part of the network, suitable counter measures needs to be kicked-in including change of security keys, isolation of the affected network branch or alerting human operator making the system resilient to any attacks. Depletion of battery power of a device can be detected and the system may re-distribute its tasks so that the burning rate can be

[2] https://www.globalsign.com/en/blog/top-iot-trends-of-2018/
[3] http://www.edgica.com/internet-of-things-in-2018/

reduced to extend its life. Extending such adaptations and self-optimization in various dimensions can enhance the overall system robustness.

The intelligence of C-IoT should also reflect in its ways for interacting with human. Five senses of human could be exploited as a means to communicate with human. It may vary with the `objectives of the interactions. A C-IoT system may receive commands and configuration inputs from human through voice, haptics or other input devices. Information about system states, events etc. could be conveyed to human through audio, vision, haptics and other output devices. Augmented Reality (AR) and Virtual Reality (VR) are emerging technologies that integrates many of these modes that are being explored for many of the human-IoT system interactions. In all these cases the C-IoT system should understand the human context and choose appropriate modality that provide optimum user experience and efficiency.

Knowledge management is an important aspect for C-IoT to help in its autonomous functionalities. This would include knowledge about the application, system architecture, resources, system state, behavior etc. It has static as well as dynamic parts and suitable learning algorithms should be deployed to support the dynamic knowledge. Recent advancements in the machine learning including deep learning can help a lot to build required learning capability in the system.

Some Motivating Use Cases

Let's look at a few interesting examples of C-IoT. Our first example is an industrial safety application. Monitoring the body vitals of the workers working in a hazardous environment and quickly responding to any abnormal events can be critical and potentially life-saving for worker safety. It can be achieved by the worker wearing a smart watch that can monitor the movement and heart beats round-the-clock and send the information to a back-end[4]. A cognitive analytics engine running in the back-end can do a knowledge-driven analytics on the collected information and raise appropriate alarms when required. The cognitive engine can look for detecting events like sudden fall, immobility and sudden fluctuations in heartbeats to generate the requisite alarms. Multitudes of sensors on the wearable have to be scheduled and configured through self-optimization so that the battery life can be extended without affecting the performance expectations. In case the wearable lose the wireless network (Low Power Wide Area Network - LPWAN) connectivity in an emergency situation, it would like to search for an alternate gateway – may be a Wi-Fi access point or users smartphone over Bluetooth to pass the critical message.

The second example is of an IoT-driven resilient process control system for a factory. In the era of Industry 4.0, a lot of factory equipment are fitted with sensors which send data to backend over an IoT-driven infrastructure for analytics and actionable insights. In a C-IoT implementation of such a system, the system can automatically switch to other sensor data or generate soft sensor outputs combining other sensor data and information in case of sensor failure. Such system can also create alternate networking routes and/or process most of the data at the network edge in order to minimize network throughput / relax latency requirements in case of disturbances in the factory wireless network. In both cases, the cognitive engine can help in improving the resilience and reliability of the IoT system.

Our third example is of a drone examining a critical outdoor infrastructure. This is a real problem for utility companies having large electricity and water distribution systems. Let's take an electricity company which wants to inspect the structural integrity of its powerline distribution towers, either as a part of routine maintenance or as a health-check up after a disaster like storm. Sending people to do this job is extremely time consuming and hazardous. Instead, we can have a drone which can autonomously navigate itself by following the powerlines by processing the images taken from its downward looking camera (such sensor driven autonomous navigation makes it a C-IoT system) and reach the distribution tower. It can inspect the tower from a distance using camera vision and try to find out high level irregularities. If it finds some problem (say an insulator cap of a high tension line seems to be damaged), it can automatically go closer to that part of the tower, zoom in, assess the damage and send real-time reports to the back office for sending a technician to repair. The drone can also self-monitor its resources (like battery life) or on-board faults to make sure it can maximize its mission objectives. In not so distant future, even the repair would be possible by the drone with a technician siting remotely in his office remotely guiding a robotic arm on the drone to perform the repair / replacement (similar to remotely operated robotic surgery). In this case, use of C-IoT not only saves money and time, but also avoids sending people to do hazardous jobs like going near high-tension electrical lines, thereby improving the overall safety.

[4] https://economictimes.indiatimes.com/tech/hardware/tatas-develop-safety-watch-for-workers-to-focus-on-wearables/articleshow/52111684.cms

Some Thoughts on Implementation Aspects

How to go about implementing a C-IoT system? We would like to share some high level thoughts here. As mentioned earlier, at the heart of a cognitive system, there is a cognitive architecture implementing a cognitive cycle. 'Sense-Understand-Decide-Act' is a generic abstract cognitive cycle that can guide the architecture of autonomic functions planned to be incorporated in the system. Learning is an integral part of the cycle that helps managing the knowledge about 'self' and 'world'. So first question on the implementation aspect is on the knowledge model and repository for the system. 'Self' model should capture the knowledge about the IoT system – sensors, network structure, states and configuration, protocols, data & control flows, security configuration etc. The world knowledge should incorporate the models of all external entities that would contribute or impact the operation of the system. It will include the target system – the system for which IoT is built for, environment factors, ambience, user state and goals, Of-course the detailing of such knowledge systems will be based on the level and scope of automation to be incorporated in the system. The knowledge model has both static and dynamic parts. The static part include ontologies, graphs, rules etc. and they have to be either specified upfront or at least part of it discovered from the system. The dynamic part is acquired from the system with suitable data analysis and inferences. From our experience, the most difficult part of a C-IoT is in building and maintaining the knowledge base that is required to the level of self-x functions we would like to incorporate.

Looking at the cognitive cycle, the 'Sense' capability is already a basic component of any IoT system. From the sensed data building up and updating the knowledge structures through analysis and inferences is the 'Understanding' capability. As a next step in the 'Decide' stage the facts and knowledge about the 'self' and 'world' is used to make various decisions and actionable insights towards achieving the stated system goals. Most cases this will include a high level planning stage as well to generate a coarse action plan. In the 'Act' stage the decisions are mapped to corresponding low level action sequences and applied on the IoT system in a timely manner. Specific algorithm candidates for implementing the above capabilities are well covered in the state of the art literature on autonomous systems and a discussion on them is out of scope of this article.

Another implementation related question is on where to embed this 'cognitive engine' encapsulating the cognitive cycle? Should it be centralized at the cloud or distributed at edges or both? For a standard IoT system also this question comes up [2]. Is the cognitive C-IoT system is any different than a standard IoT system from this perspective? What we need to remember for a cognitive system is that it incorporates a cognitive cycle which is a control loop. The system should satisfy the control theoretic expectations on response time, actuations etc. so that the overall system is stable. The architecture should be chosen accordingly.

Today C-IoT has started gathering research interests but yet to reach real Industrial deployments in its true sense of self-x systems. More and more research and implementation challenges are expected to emerge as we progress towards pilot studies and field implementations.

References

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About the authors

Arpan Pal received both his B.Tech and M.Tech from Indian Institute of Technology, Kharagpur, India in Electronics and Telecommunications and PhD. from Aalborg University Denmark. He has more than 26 years of experience in the area of Signal Processing, Communication, Embedded Systems and Robotics. Currently he is with Tata Consultancy Services (TCS), where, as Principal Scientist, he is heading the Embedded Systems and Robotics Research in TCS. He has more than 125 publications and book chapters till date in reputed Journals and Conferences. He has also co-authored a complete book on IoT. He has filed for more than 95 patents and has 38 patents granted to him. He is on the editorial board for reputed journals like ACM Transactions on Embedded Computing Systems, IEEE Transactions on Emerging Topics in Computing and IT Professional Magazine from IEEE Computer Society. He is a Senior Member of IEEE and is also engaged in the innovation space in different industry bodies like Confederation of Indian Industries (CII), Bengal Chamber of Commerce and Industries (BCC&I) and National Association of Software and Services Companies (NASSCOM). He is on the board of studies and review committees of different engineering institutes and also engaged as technology mentor for some of the start-up accelerators.

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Life Lesson from Xi Jing Peng, President of China

President Xi Jing Peng of China said:

When I was a small child, I was very selfish; I would always grab the best for myself. Slowly, everyone left me and I had no friends. I didn't think it was my fault so I criticized others.

My father gave me 3 sentences to help me in life.

One day, my father cooked 2 bowls of noodles put the 2 bowls on the table. One bowl had one egg on top and the other bowl did not have any egg on top. He said "My child. You choose. Which bowl do you want". Eggs were hard to come by those days! We only got to eat eggs during festivals or New Year. Of course I chose the bowl with the egg! As we started eating. I was congratulating myself on my wise choice/decision and eat up the egg. Then to my surprise, as my father ate his noodles, there were TWO eggs at the bottom of his bowl beneath the noodles! I regretted my choice so much and scolded myself for being too hasty in my decision. My father smiled and said to me, "My child. You must remember, what your eyes see may not be true. If you are intent on taking advantage of people, you will end up losing!"

The next day, my father again cooked 2 bowls of noodles: one bowl with an egg on top and the other bowl with no egg on top. Again, he put the two bowls on the table and said to me, "My child, you choose. Which bowl do you want?" This time I thought I was smarter. I chose the bowl without any egg on top. To my surprise, as I separated the noodles on top, there was not even a single egg at the bottom of the bowl! Again my father smiled and said to me, "My child, you must not always rely on experiences because sometimes, life can cheat you or play tricks on you. But you must not get annoyed or be sad. Just treat this as learning a lesson .You cannot learn this from textbooks.

The third day, my father again cooked 2 bowls of noodles, again one bowl with an egg on top and the other bowl with no egg on top. He put the 2 bowls on the table and again said to me, "My child. You choose. Which bowl do you want?". This time, I told my father, "Dad, you choose first. You are the head of the family and contributed the most to the family. "My father did not decline and chose the bowl with one egg on top. As I ate my bowl of noodles, I was sure in my heart that there was no egg inside the bowl. To my surprise! There were TWO eggs at the bottom of the bowl.

My father smiled at me with love in his eyes, "My child, you must remember that when you think for the good of others, good things will always naturally happen to u!"

I always remember these 3 sentences of my father and lived and do my business accordingly. True enough, my business was a roaring success.

-- Xi Jing Peng

Xiaomi has launched a smart dustbin which opens automatically using sensors to detect human hand or other objects within a distance of 0-35 cm. It also has the ability to seal the garbage bag once it is full and can automatically replace it with a fresh bag. Priced at ₹2000, the dustbin is expected to begin shipping from September.

A 26-year-old homeless web developer in California, David Casarez received over 200 job offers after he stood at a busy street and distributed his CVs. His story went viral on the Net after a passerby took his picture and posted it online urging others to support him. David claimed Google, Bitcoin.com and a bunch of startups offered him a job.